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RESEARCH MEMORANDUM

PERFORMANCE EVALUATION OF REDUCED-CHORD ROTOR BLADING AS APPLIED TO J73 TWO-STAGE TURBINE

II - OVER-ALL PERFORMANCE AT INLET CONDITIONS OF 35 INCHES OF MERCURY ABSOLUTE AND 700° R

By Harold J. Schum, John J. Rebeske, Jr., and Robert E. Forrette

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

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PERFORMANCE EVALUATION OF REDUCED-CHORD ROTOR BLADING AS APPLIED TO J73 TWO-STAGE TURBINE

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SUMMARY

In an effort to reduce the weight of the J73 turbojet engine, an investigation was made to ascertain the feasibility of utilizing reduced-chord rotor blading on the two-stage turbine. The manufacturer's alternative turbine was operated as a component over a range of speeds and over-all pressure ratios at turbine-inlet conditions corresponding to 35 inches of mercury absolute and 700° R, and the turbine performance characteristics were determined. These results were compared with the results of a previous performance evaluation which was conducted with the same turbine equipped with the standard rotor-blading configuration.

The peak brake internal efficiency obtained with the reduced-chord turbine was slightly less than 0.91 and occurred at an over-all pressure ratio of approximately 3.0 and 110 percent of design equivalent rotor speed. At the design equivalent speed and at a work output just sufficient to drive the compressor, the turbine operated with an efficiency slightly over 0.90 at an over-all pressure ratio of 2.75. The reduced-chord blading modification resulted in an observed decrease in the peak efficiency of approximately 0.01. The efficiency decrease at the design operating point was even less. The observed equivalent air weight flows for both turbine configurations were comparable at the design operating point and slightly greater than that of the design value.

When the turbine was equipped with the reduced-chord rotor blades, a decrease in torque output was observed at pressure ratios above 2.2 as compared with the torque obtained with the standard rotor blades at all speeds investigated. This decrease in torque output for the reduced-chord turbine, which is probably caused by the increased blockage of the second-stage rotor-exit annular area, results in turbine operation nearer to limiting loading.

[1]The information presented herein was previously given limited distribution.

At the particular test conditions investigated, the use of reduced-chord rotor blades on the J73 turbine effected a weight saving of over 40 percent when compared with the standard turbine rotor-blade and disk weights, with a corresponding relatively slight expense to turbine over-all performance.

INTRODUCTION

The NACA Lewis laboratory is currently investigating the two-stage turbine from the J73 turbojet engine in order to determine the over-all performance characteristics with various turbine-blading configurations and various turbine-inlet conditions. The over-all performance of the J73 turbine with standard rotor blading at inlet conditions of 35 inches of mercury absolute and 700° R is presented in reference 1. The turbine operated with a maximum brake internal efficiency of slightly less than 0.92 at an over-all pressure ratio of approximately 3.4 and 120 percent of design equivalent speed. At the equivalent design speed and a value of equivalent work output just sufficient to drive the compressor, the turbine operated with a brake internal efficiency of approximately 0.91. 2871

The purpose of this report is to determine (1) the feasibility of utilizing reduced-chord rotor blades as a method of reducing engine weight and (2) the penalties in over-all performance, if any, that would be incurred in a turbine with such a blading configuration. Utilization of reduced-chord rotor blades would permit the use of thinner turbine rotor disks and thereby reduce over-all component weight and inertia so that engine acceleration characteristics could be improved.

For this investigation the standard turbine was modified to incorporate first-stage rotor blades that were one-half the chord length of the standard blades. The normal second-stage rotor blading was also modified by altering the blade chord to approximately two-thirds of its normal chord. The number of blades was increased in order to maintain an approximate constant blade solidity between the standard and the modified turbine configurations. The rotor-blade profiles for the two turbines were geometrically similar except for the trailing-edge thicknesses. The original, or standard, stators were used in the modified turbine investigation.

The modified turbine was investigated over a range of speeds from 20 to 130 percent of design and over a range of total-pressure ratios from 1.4 to 4.0. The unit was operated at constant nominal values of inlet conditions of 35 inches of mercury absolute and 700° R. The over-all performance results are presented in terms of brake internal efficiency and equivalent work output (both based upon torque measurements), equivalent total-pressure ratio, equivalent speed, and equivalent weight flow. The method of deriving the equivalent parameters is presented in reference 1. The results of the turbine investigation obtained herein are compared with those obtained in reference 1 and are tabulated for the convenience of the reader.

SYMBOLS

The following symbols are used in this report:

E	enthalpy drop based on torque measurements, Btu/lb
N	rotational speed, rpm
p	static pressure, in. Hg abs
p'	total pressure, in. Hg abs
p'_x	total pressure plus velocity pressure corresponding to axial component of velocity, in. Hg abs
T'	total temperature, $^{\circ}R$
V	velocity
w	weight flow, lb/sec
$\frac{wN}{60\delta}\epsilon$	weight-flow parameter based on equivalent weight flow and equivalent rotor speed
γ	ratio of specific heats
δ	ratio of inlet-air pressure to NACA standard sea-level pressure, $p_1'/29.92$ in. Hg abs
ϵ	function of γ, $\frac{\gamma_0}{\gamma_e}\left[\frac{\left(\frac{\gamma_e+1}{2}\right)^{\frac{\gamma_e}{\gamma_e-1}}}{\left(\frac{\gamma_0+1}{2}\right)^{\frac{\gamma_0}{\gamma_0-1}}}\right]$
η_i	brake internal efficiency defined as ratio of actual turbine work based on torque measurements to ideal turbine work based on inlet total pressure p_1' and outlet total pressure corrected for whirl $p'_{x,2}$

θ_{cr} squared ratio of critical velocity to critical velocity at NACA standard sea-level temperature of 518.4° R $(V_{cr,e}/V_{cr,0})^2$

τ torque, ft-lb

Subscripts:

cr critical 2871

e engine operating conditions

x axial

0 NACA standard sea-level conditions

1 turbine-inlet measuring station

2 turbine-outlet measuring station

APPARATUS

The two-stage turbine from the J73 turbojet engine used in this investigation is described in detail in reference 1. The sea-level design conditions as supplied by the engine manufacturer and the design equivalent conditions are as follows:

	Engine sea-level design conditions, zero ram	Equivalent design conditions
Weight flow, lb/sec	138.7	42.05
Rotational speed, rpm	7950	4041
Inlet temperature, °R	2060	518.4
Inlet pressure, in. Hg abs	201	29.92

A photograph of the over-all turbine experimental setup is shown in figure 1. A schematic diagram of the component assembly is presented in figure 2(a). Air was supplied to the turbine by the laboratory combustion-air system. The air passed through a submerged A.S.M.E. flat-plate orifice located in a straight section of the inlet piping; a bypass mixing system permitted some of the air to be heated by means of two commercial jet-engine burners. The air was then ducted to the turbine proper. By regulating the amount of bypassed air and fuel flow, the air temperature to the turbine inlet could be maintained constant. The air then passed through the turbine and tail cone into the laboratory altitude-exhaust facilities. Turbine power output was absorbed by two cradled dynamometers of the eddy-current wet-gap type connected in tandem.

In this investigation, the turbine rotor blades were modified from those of the standard turbine described in reference 1 and shown in figure 2(b). The axial chord of the first-stage rotor blades was decreased by one-half, and the axial chord of the second-stage rotor blades was decreased by one-third. A proportionate decrease in rotor-disk thicknesses was also effected and can be observed by comparing figures 2(b) and 2(c). The number of blades was increased in both stages to maintain approximately the same solidity values that prevailed for the standard rotor blades. The standard turbine rotors had 57 blades in the first stage and 47 blades in the second stage; the reduced-chord turbine was equipped with 114 and 74 rotor blades in the first and second stages, respectively. The rotor-blade profiles were geometrically similar for both rotor configurations with the exception of the trailing-edge thickness. The trailing-edge thicknesses of the reduced-chord blades were not reduced in the same proportion as the blade profiles, because of mechanical limitations. These modified rotors, hereinafter referred to as the reduced-chord rotors, were investigated with the standard turbine stators. By decreasing the axial chord lengths of the blades and reducing the thickness of the two rotor disks, a saving of over 200 pounds of turbine component weight was effected. This saving in turbine weight represents over 40 percent of the standard J73 rotor-blade and disk weights.

INSTRUMENTATION

The instrumentation required for the determination of the reduced-chord turbine over-all performance was the same as that described completely in reference 1. Turbine air flow was metered by the A.S.M.E. submerged orifice located in the inlet ducting. The gas state in the turbine was measured at the inlet and outlet of the blading as indicated in figure 2(a).

Air pressures were indicated on mercury manometers, and temperatures were measured with calibrated iron-constantan thermocouples in conjunction with a highly sensitive potentiometer. Fuel flow was measured by a calibrated rotameter; turbine speed, by an electric chronometric tachometer; and turbine torque output, by a calibrated NACA balanced-diaphragm-type thrustmeter.

The precision of the measurements taken to determine the performance of the J73 two-stage turbine is estimated to be within the following limits:

Temperature, °R	±1.0
Pressure, in. Hg	±0.10
Air weight flow, percent	±1.0
Rotor speed, percent	±0.5
Torque, percent	±0.5

METHODS AND PROCEDURE

Turbine-inlet total pressure p_1' was calculated from the average inlet static-pressure readings, the average inlet total temperature, the known annulus area, and the orifice air weight flow plus the fuel weight flow. The calculation for inlet total pressure was necessary because of the observed circumferential total-pressure variation which existed and is discussed in detail in reference 1. Turbine-outlet total pressure $p_{x,2}'$ is defined as the static pressure at the discharge of the second 2871
rotor plus the velocity pressure corresponding to the axial component of the absolute rotor-outlet velocity. Thus, the calculated value of $p_{x,2}'$ charged the turbine for the energy of the rotor-exit tangential velocity. The methods employed in computing the inlet and the outlet total pressures and the method of determining the equivalent conditions of the turbine with appropriate variations in the ratio of specific heats γ with turbine-inlet temperature are either derived or explained in reference 1.

The turbine was operated at constant nominal inlet values of total pressure and temperature of approximately 35 inches of mercury absolute and 700° R, respectively. The temperature was maintained constant by regulating the amount of fuel flow to the burners.

A nominal over-all total-pressure ratio $p_1'/p_{x,2}'$ was imposed across the turbine, and the speed was varied from 20 to 130 percent of the equivalent design value. The over-all pressure ratio was varied from approximately 1.4 to 4.0. At the low speeds, however, the pressure-ratio range was limited by the inherent torque characteristics of the dynamometers.

RESULTS AND DISCUSSION

The over-all performance of the two-stage J73 turbine equipped with reduced-chord rotors is presented, similarly to that of the J73 turbine with the standard rotors (ref. 1), in terms of equivalent shaft work, equivalent weight flow, brake internal efficiency, equivalent total-pressure ratio, and percentage of equivalent design rotor speed. All performance parameters presented herein have been corrected to NACA standard sea-level conditions corresponding to 29.92 inches of mercury absolute and 518.4° R.

The variation of equivalent shaft work $E/\theta_{cr,1}$ with a weight-flow parameter $(wN/60\delta_1)\epsilon$ for constant values of over-all total-pressure ratio $p_1'/p_{x,2}'$ and equivalent rotor speed $N/\sqrt{\theta_{cr,1}}$ is presented in figure 3(a). Brake internal efficiency contours η_i are also included. Reference 1 has indicated that from compressor design specifications a turbine equivalent shaft work output of 28.48 Btu per pound was required. This design operating point is shown on figure 3(a) at the design equivalent speed and occurred at an over-all pressure ratio of approximately 2.75 and an efficiency value slightly greater than 0.90, which is within the region of the maximum-obtained efficiency.

Because the principal objective of this report is to compare the over-all performance characteristics of the standard turbine with those of the reduced-chord rotor-bladed turbine, the performance map of the standard configuration is reproduced in figure 3(b). Comparison of the two performance maps (fig. 3) indicates that the equivalent shaft work obtained for both turbine configurations is comparable for pressure ratios of 2.2 to 2.8 over the entire speed range investigated. At rotor speeds of 80 percent of equivalent design rotor speed and above, and at pressure ratios less than 2.2, the equivalent shaft work obtained is greater for the reduced-chord turbine than for the standard turbine; at pressure ratios of 3.2 and above, however, the work output for the standard turbine is slightly greater than for the reduced-chord turbine.

The peak efficiency obtained with the standard rotors was slightly less than 0.92 and occurred at a pressure ratio of approximately 3.4 and 120 percent of equivalent design speed (ref. 1). For the reduced-chord turbine, however, this peak efficiency was slightly less than 0.91 and occurred at 110 percent of equivalent design speed at a pressure ratio of approximately 3.0. Thus, when the turbine-blading and disk weight was decreased by over 40 percent by reducing the blade-chord and disk thicknesses, the peak efficiency decreased approximately 0.01; the decrease in efficiency at the design operating point was even less. In general, the efficiency obtained at the elevated pressure ratios with the reduced-chord rotors was less than that observed for the standard rotors. This difference is shown more clearly in figure 4, where the variation of over-all brake internal efficiency with over-all total-pressure ratio at the design speed is presented for the two rotor configurations. With the turbine rotors modified with the reduced-chord blades, the slight decrease in efficiency at the equivalent design speed and work can be observed. It will also be noted that the modified turbine operated more efficiently at pressure ratios less than 2.2, while the inverse occurred at higher pressure-ratio values. Although figure 4 presents data for the design speed, the observed variations are representative of those at other speeds near that of design.

The variation of equivalent weight flow with over-all total-pressure ratio for the various rotor speeds investigated is shown in figure 5. Comparison of this curve with the corresponding curve obtained with the standard rotor-blading configuration (ref. 1) indicates a slight decrease in weight flow for the reduced-chord turbine for all speeds investigated. In the choked region this difference, which amounted to approximately 0.3 pound per second at all speeds, represented only 0.7 percent of the total weight flow, which was within the aforementioned measuring accuracy. Figure 5 indicates that the first stator chokes the flow at speeds up to and including 70 percent of the design equivalent speed. As the speed is further increased, however, the choking weight flow decreases accordingly, which indicates that the flow is choking somewhere downstream of the first stator. It is of further interest to note on figure 5 that the observed equivalent weight flow at design speed and equivalent design pressure ratio for the reduced-chord rotors was 42.27 pounds per second, which was slightly greater than that of the design value of 42.05. The corresponding value obtained for the standard turbine configuration was 42.65 pounds per second. 2871

The variation of equivalent torque output with over-all total-pressure ratio is shown in figure 6 for both the turbine with the reduced-chord rotor blades and the turbine having standard rotor blades (ref. 1) for all speeds investigated. It can be noted that the torque values for the two turbine-blading configurations at pressure ratios less than 2.2 are comparable. However, at the higher pressure ratios, the torque output for the reduced-chord rotors was less than that observed for the standard rotor blades. The decreased slope of the torque curves at the elevated pressure ratios indicates a definite approach to the turbine limiting loading point, defined as the point of turbine operation at which any further increase in pressure ratio across the turbine results in no additional turbine work output. The apparent approach to limiting loading is further evidenced when the rotor-exit Mach number is considered. The rotor-exit axial Mach number was calculated from the static-to-total pressure ratio $p_2/p'_{x,2}$ at the turbine-exit measuring station and the tables from reference 2. Additional calculations, made from the blade-drawing specifications at the mean section, indicated that the trailing-edge blockage of the second-stage rotor increased from 5.25 to 6.49 percent of the annular area when the reduced-chord rotor blades were installed. When an over-all pressure ratio of 3.90 is selected as a basis for comparison, the variation of second-stage rotor-exit axial Mach number with percentage of annular-area blockage for the two turbines at identical operating conditions is shown by the two points on figure 7. Also shown is the Mach number curve as a function of the trailing-edge blockage for limiting loading conditions as obtained from a cross plot of the analysis presented in reference 3. Observation of figure 7 readily indicates that the turbine operating with reduced-chord rotor blades more nearly approaches limiting loading than does the turbine with standard rotor blading. The decrease in equivalent torque at the higher pressure ratios (fig. 6) with the reduced-chord rotor blading is probably caused by the approach to limiting loading with the corresponding increase in losses associated with the higher Mach numbers and results, therefore, in the aforementioned efficiency variations shown in figure 4.

From the foregoing discussion, it can be concluded that for the test conditions investigated, the use of reduced-chord turbine rotor blading as applied herein to the J73 turbine resulted in a considerable saving of component weight at a relatively slight expense to turbine performance when compared with that which was obtained with standard rotor blading.

Additional pertinent information obtained from the experimental investigation described herein is presented in a data summary, table I. Included are values of calculated over-all total-pressure ratio $p_1'/p_{x,2}'$, over-all total-pressure ratio p_1'/p_2', over-all total-to-static pressure ratio p_1'/p_2, inlet total pressure p_1', inlet total temperature T_1', outlet total temperature T_2', turbine speed N, weight flow w, and torque τ, from which all points on the performance map (fig. 3(a)) were calculated.

SUMMARY OF RESULTS

From an investigation of the over-all performance of the J73 two-stage turbine modified to incorporate reduced-chord rotor blading, the following results were obtained:

1. At the design equivalent speed and at a work output just sufficient to drive the compressor, the turbine operated with a brake internal efficiency slightly greater than 0.90.

2. A peak brake internal efficiency slightly less than 0.91 was obtained at an over-all pressure ratio of approximately 3.0 and at 110 percent of design equivalent rotor speed.

3. Utilization of reduced-chord turbine rotor blading effected a weight saving of more than 40 percent when compared with the weight of the standard rotor blades and disks and caused an observed decrease in peak efficiency of approximately 0.01 as compared with results obtained with standard rotors. The efficiency decrease at the design operation point was even less.

4. The observed equivalent air weight flow at the design operating point was 42.27 pounds per second as compared with 42.65 pounds per second obtained for the standard turbine. Both values, however, were slightly higher than the design value of 42.05 pounds per second.

5. At over-all pressure ratios greater than 2.2, the equivalent torque output was less for the reduced-chord turbine than for the standard turbine at all speeds investigated. This decrease in torque can probably be attributed to the increased blockage of the second-stage rotor-blade-exit annular area, which resulted in turbine operation nearer limiting loading.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics 2871
Cleveland, Ohio, February 12, 1953

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2. The Staff of the Ames 1- by 3-Foot Supersonic Wind-Tunnel Section: Notes and Tables for Use in the Analysis of Supersonic Flow. NACA TN 1428, 1947.

3. English, Robert E., Silvern, David H., and Davison, Elmer H.: Investigation of Turbines Suitable for Use in a Turbojet Engine with High Compressor Pressure Ratio and Low Compressor-Tip Speed. I - Turbine-Design Requirements for Several Engine Operating Conditions. NACA RM E52A16, 1952.

TABLE I. - DATA SUMMARY FROM EXPERIMENTAL INVESTIGATION OF

J73 TWO-STAGE TURBINE WITH REDUCED-CHORD ROTOR BLADING

Calculated over-all total-pressure ratio, $p_1'/p_{x,2}'$	Over-all total-pressure ratio, p_1'/p_2'	Over-all total-to-static pressure ratio, p_1'/p_2	Inlet total pressure, p_1', in. Hg abs	Inlet total temperature, T_1', °R	Outlet total temperature, T_2', °R	Engine speed, N, rpm	Weight flow, w, lb/sec	Torque, τ, ft-lb
1.334	1.321	1.370	34.58	700.5	666.5	946	38.06	2165
1.336	1.339	1.368	34.74	701.2	655.3	1879	36.60	1590
1.341	1.340	1.371	34.61	700.2	648.1	2824	34.77	1120
1.345	1.328	1.373	34.73	701.4	650.4	3297	34.30	923
1.356	1.319	1.384	34.81	699.3	651.1	3770	33.94	753
1.353	1.302	1.381	34.68	700.2	655.8	4248	33.55	589
1.355	1.287	1.383	34.80	699.7	660.9	4716	33.43	458
1.360	1.273	1.388	34.66	699.8	667.1	5186	33.31	338
1.509	1.456	1.568	34.66	702.0	661.6	948	40.34	2784
1.491	1.489	1.545	34.48	701.1	641.2	1887	39.79	2187
1.501	1.502	1.551	34.76	700.4	631.1	2823	38.67	1651
1.492	1.487	1.539	34.45	700.5	630.3	3307	37.71	1400
1.503	1.487	1.551	34.64	701.4	632.1	3772	37.30	1202
1.512	1.473	1.559	34.57	700.4	631.5	4249	36.96	1032
1.522	1.463	1.570	34.69	701.4	637.8	4721	36.73	852
1.546	1.459	1.595	34.87	701.0	644.5	5191	36.49	677
1.546	1.432	1.595	34.62	700.3	647.6	5664	36.61	573
1.701	1.678	1.789	34.59	700.4	628.3	1884	41.58	2737
1.699	1.701	1.782	34.55	701.1	616.1	2826	40.83	2180
1.708	1.703	1.790	34.63	701.5	612.8	3295	40.34	1928
1.708	1.696	1.787	34.58	701.2	610.8	3774	39.81	1687
1.719	1.693	1.797	34.58	701.6	610.6	4244	39.38	1475
1.717	1.669	1.792	34.61	701.9	615.0	4717	38.91	1261
1.721	1.644	1.797	34.48	700.8	618.1	5189	38.67	1070
1.741	1.630	1.819	34.57	701.0	623.4	5662	38.59	912
1.739	1.599	1.817	34.56	701.5	630.9	6140	38.38	747
1.984	1.912	2.133	34.45	702.1	618.2	1882	42.23	3296
1.975	1.961	2.114	34.44	702.4	600.5	2823	41.85	2706
1.946	1.949	2.077	34.33	701.7	595.4	3301	41.56	2405
1.970	1.971	2.102	34.54	700.8	591.1	3778	41.35	2153
1.966	1.948	2.093	34.58	701.7	591.5	4242	40.94	1896
1.983	1.959	2.111	34.54	701.3	589.5	4713	40.59	1683
1.976	1.920	2.101	34.43	701.3	592.6	5187	40.14	1475
1.977	1.886	2.100	34.55	701.8	598.5	5660	40.07	1273
1.998	1.872	2.125	34.62	701.0	603.6	6144	39.94	1092

2871

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TABLE I. - DATA SUMMARY FROM EXPERIMENTAL INVESTIGATION OF J73

TWO-STAGE TURBINE WITH REDUCED-CHORD ROTOR BLADING - Continued

Calculated over-all total-pressure ratio, $p_1'/p_{x,2}'$	Over-all total-pressure ratio, p_1'/p_2'	Over-all total-to-static pressure ratio, p_1'/p_2	Inlet total pressure, p_1', in. Hg abs	Inlet total temperature, T_1', °R	Outlet total temperature, T_2', °R	Engine speed, N, rpm	Weight flow, w, lb/sec	Torque, τ, ft-lb
2.223	2.092	2.437	34.44	701.7	607.7	1888	42.33	3594
2.192	2.156	2.391	34.28	700.8	587.3	2821	42.23	3020
2.175	2.161	2.365	34.36	701.6	581.5	3300	42.11	2752
2.193	2.222	2.384	34.59	701.7	576.4	3773	41.95	2501
2.188	2.170	2.372	34.53	701.2	575.6	4240	41.58	2206
2.204	2.167	2.387	34.56	701.7	574.4	4713	41.30	1987
2.202	2.170	2.381	34.53	701.0	573.9	5194	40.97	1763
2.210	2.137	2.389	34.36	702.1	578.0	5662	40.57	1561
2.225	2.120	2.406	34.57	701.2	582.6	6139	40.50	1369
2.594	2.302	2.947	34.48	701.1	594.7	1883	42.39	3966
2.535	2.426	2.852	34.48	701.2	574.0	2827	42.40	3376
2.511	2.471	2.814	34.47	701.8	566.4	3316	42.34	3086
2.524	2.500	2.826	34.48	701.8	559.7	3776	42.19	2852
2.538	2.553	2.839	34.52	701.8	554.9	4243	41.92	2584
2.502	2.502	2.785	34.53	700.9	555.4	4720	41.67	2294
2.510	2.472	2.789	34.61	701.3	556.8	5190	41.53	2070
2.511	2.480	2.789	34.45	701.6	557.6	5661	41.14	1851
2.523	2.416	2.799	34.59	701.7	562.1	6133	40.95	1660
2.936	2.653	3.463	34.35	702.0	564.9	2833	42.22	3685
2.879	2.739	3.364	34.38	700.9	555.4	3304	42.22	3385
2.905	2.806	3.399	34.43	701.2	547.0	3790	42.19	3166
2.915	2.836	3.399	34.43	702.1	542.6	4253	41.94	2909
2.868	2.872	3.321	34.41	702.3	539.0	4721	41.76	2614
2.897	2.885	3.358	34.42	701.8	536.1	5191	41.64	2390
2.937	2.864	3.414	34.48	701.5	536.5	5661	41.49	2182
2.853	2.797	3.284	34.38	701.7	543.7	6136	41.26	1937
3.227	2.788	3.972	34.40	701.8	557.8	2830	42.29	3832
3.264	2.966	4.036	34.43	701.8	547.2	3303	42.30	3592
3.208	3.009	3.921	34.39	701.0	536.2	3770	42.30	3324
3.216	3.053	3.914	34.44	701.6	530.7	4244	42.21	3078
3.175	3.114	3.836	34.29	701.5	526.3	4712	41.88	2794
3.207	3.264	3.875	34.60	701.1	521.4	5189	41.85	2587
3.229	3.254	3.901	34.52	701.2	519.7	5655	41.59	2368
3.164	3.107	3.782	34.49	701.8	527.3	6136	41.33	2111

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2871

TABLE I. - DATA SUMMARY FROM EXPERIMENTAL INVESTIGATION OF J73

TWO-STAGE TURBINE WITH REDUCED-CHORD ROTOR BLADING - Concluded

Calculated over-all total-pressure ratio, $p_1'/p_{x,2}'$	Over-all total-pressure ratio, p_1'/p_2'	Over-all total-to-static pressure ratio, p_1'/p_2	Inlet total pressure, p_1', in. Hg abs	Inlet total temperature, T_1', °R	Outlet total temperature, T_2', °R	Engine speed, N, rpm	Weight flow, w, lb/sec	Torque, τ, ft-lb
3.588	2.945	4.760	34.37	701.5	550.6	2832	42.40	3975
3.689	3.136	4.990	34.53	702.4	538.8	3299	42.40	3745
3.756	3.344	5.162	34.48	701.3	526.9	3775	42.31	3505
3.666	3.395	4.836	34.53	701.8	516.9	4712	42.02	3008
3.714	3.561	4.920	34.54	702.2	512.8	5193	41.67	2773
3.670	3.721	4.833	34.46	700.8	508.2	5664	41.59	2549
3.611	3.611	4.646	34.52	701.7	510.2	6135	41.34	2298
3.701	3.131	5.034	34.53	701.3	537.9	3301	42.52	3751
3.778	3.345	5.223	34.42	700.9	526.6	3768	42.24	3499
3.819	3.459	5.317	34.56	700.8	519.4	4238	42.32	3292
3.893	3.505	5.477	34.45	702.2	515.8	4712	41.86	3035
3.818	3.633	5.232	34.48	701.4	511.1	5288	41.80	2789
3.819	3.849	5.253	34.41	701.4	507.6	5666	41.62	2565
3.800	3.813	5.145	34.47	701.9	507.4	6132	41.35	2358
3.752	3.334	5.163	34.44	701.3	526.8	3767	42.35	3510
3.853	3.433	5.379	34.64	701.7	520.4	4240	42.17	3281
3.898	3.503	5.483	34.54	701.8	515.1	4710	41.95	3051
3.983	3.713	5.765	34.53	701.3	510.1	5189	41.83	2822
4.040	3.889	5.983	34.46	701.5	507.4	5661	41.56	2609
4.099	3.908	6.215	34.43	701.3	506.1	6137	41.42	2407

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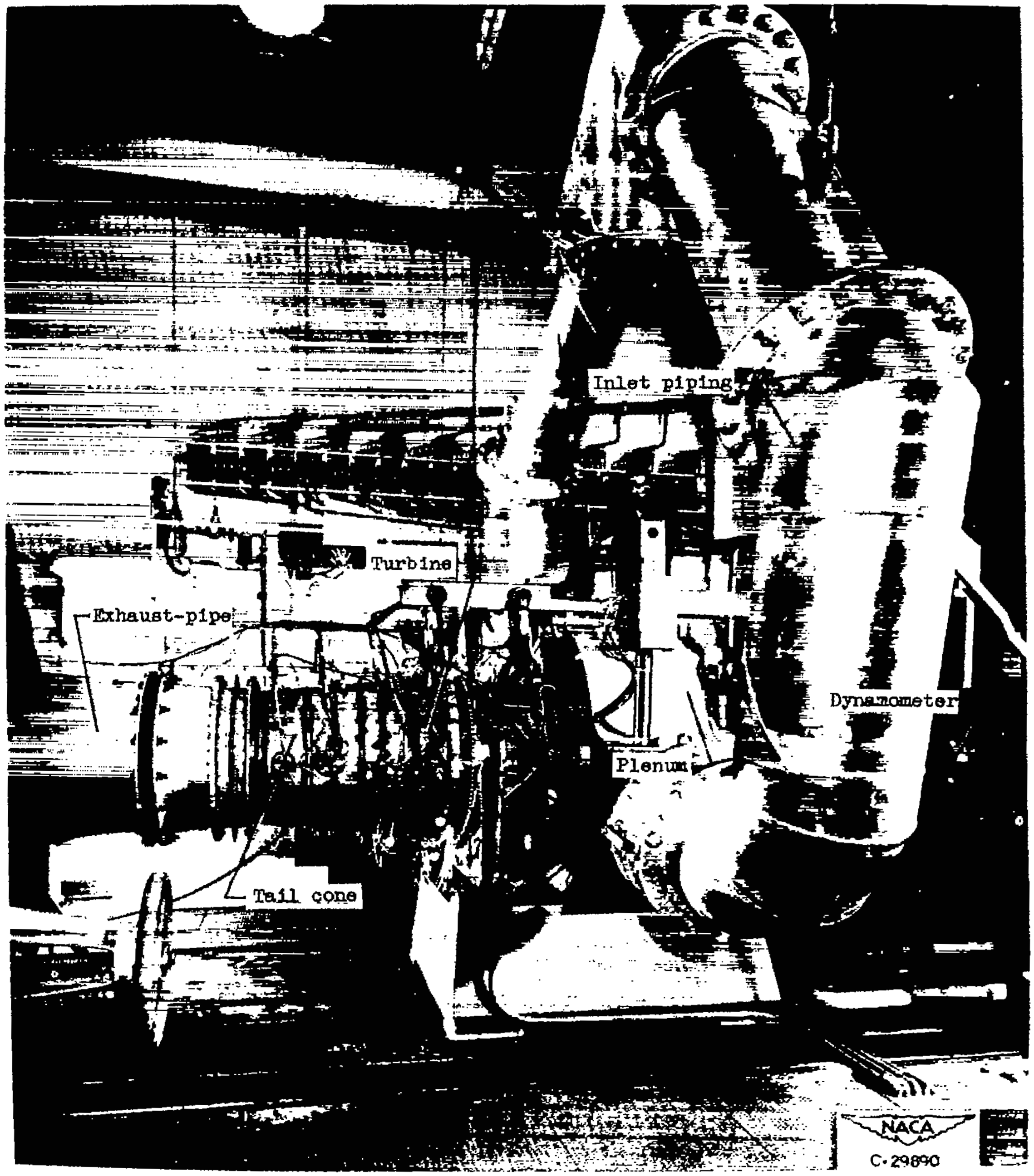

Figure 1. - Installation for experimental investigation of J73 two-stage turbine showing inlet plenum, power absorbers, and instrumentation.

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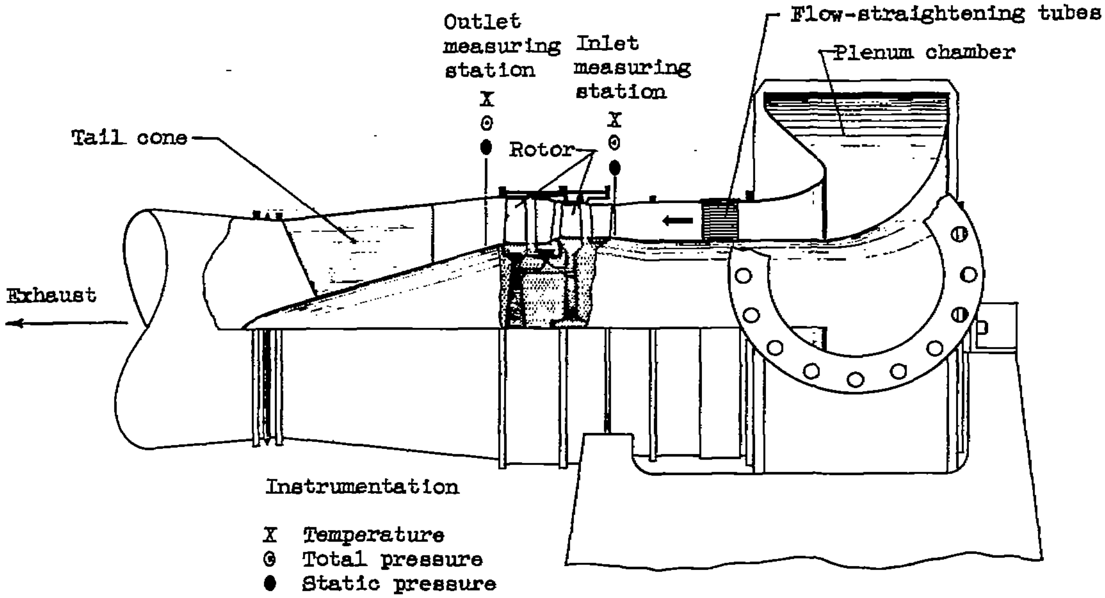
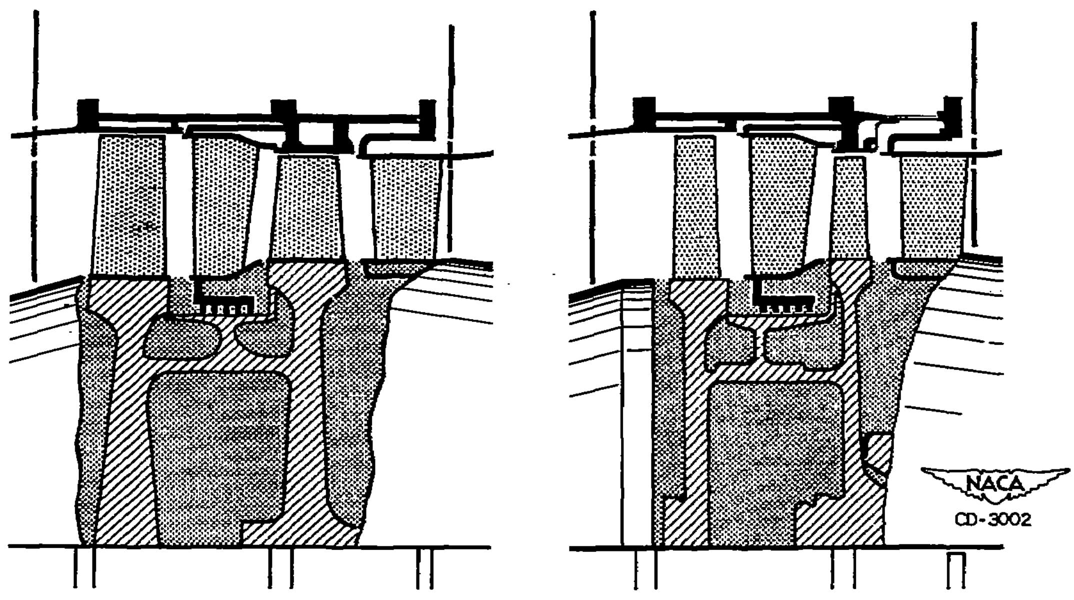
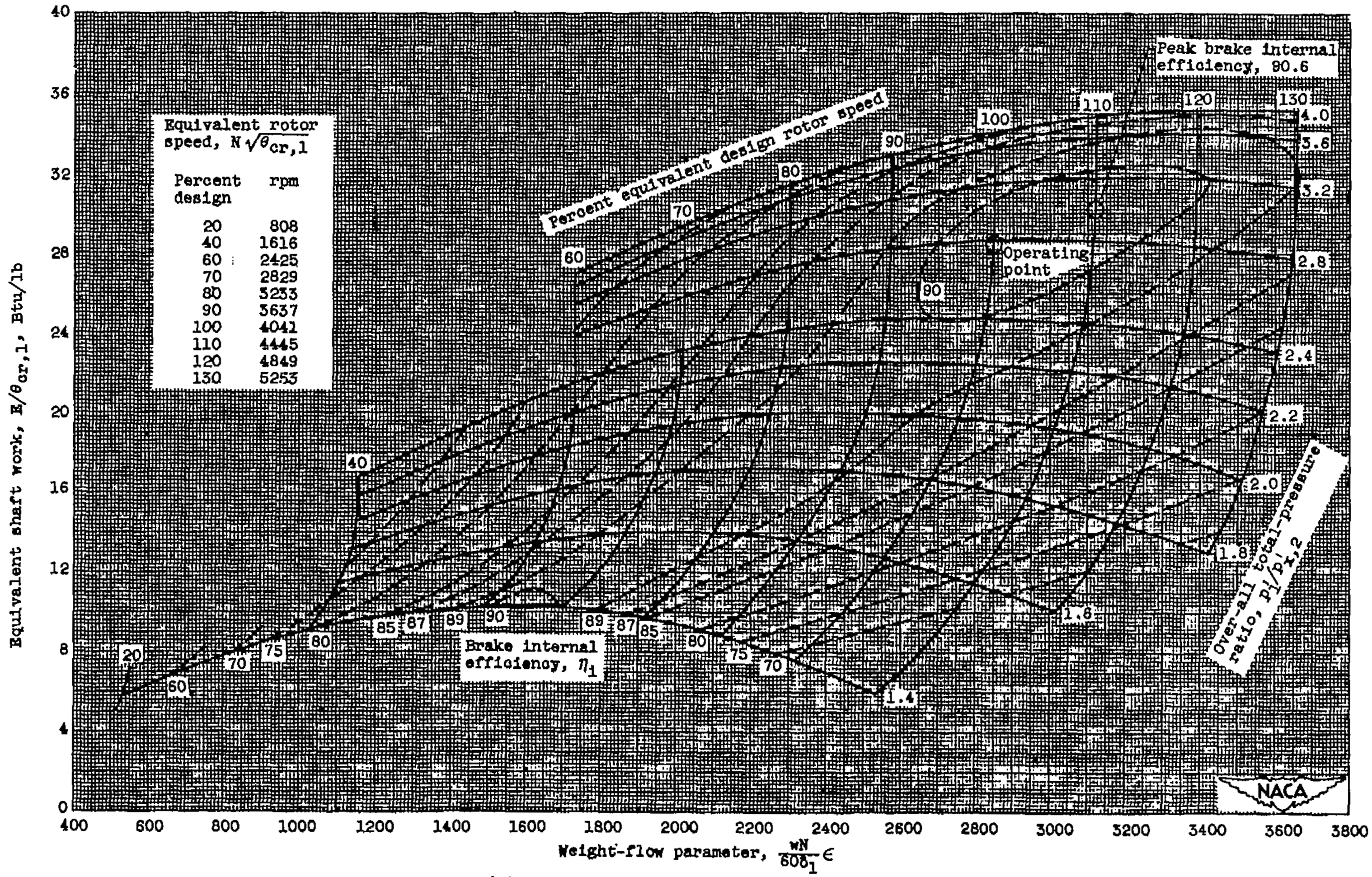


(a) Over-all turbine setup.



(b) Turbine with standard rotor blades. (c) Turbine with reduced-chord rotor blades.

Figure 2. - Schematic diagram of turbine assembly and instrumentation.



(a) Equipped with reduced-chord rotor blading.

Figure 3. - Over-all performance of J73 two-stage turbine. Turbine-inlet pressure, 35 inches of mercury absolute; turbine-inlet temperature, 700° R.

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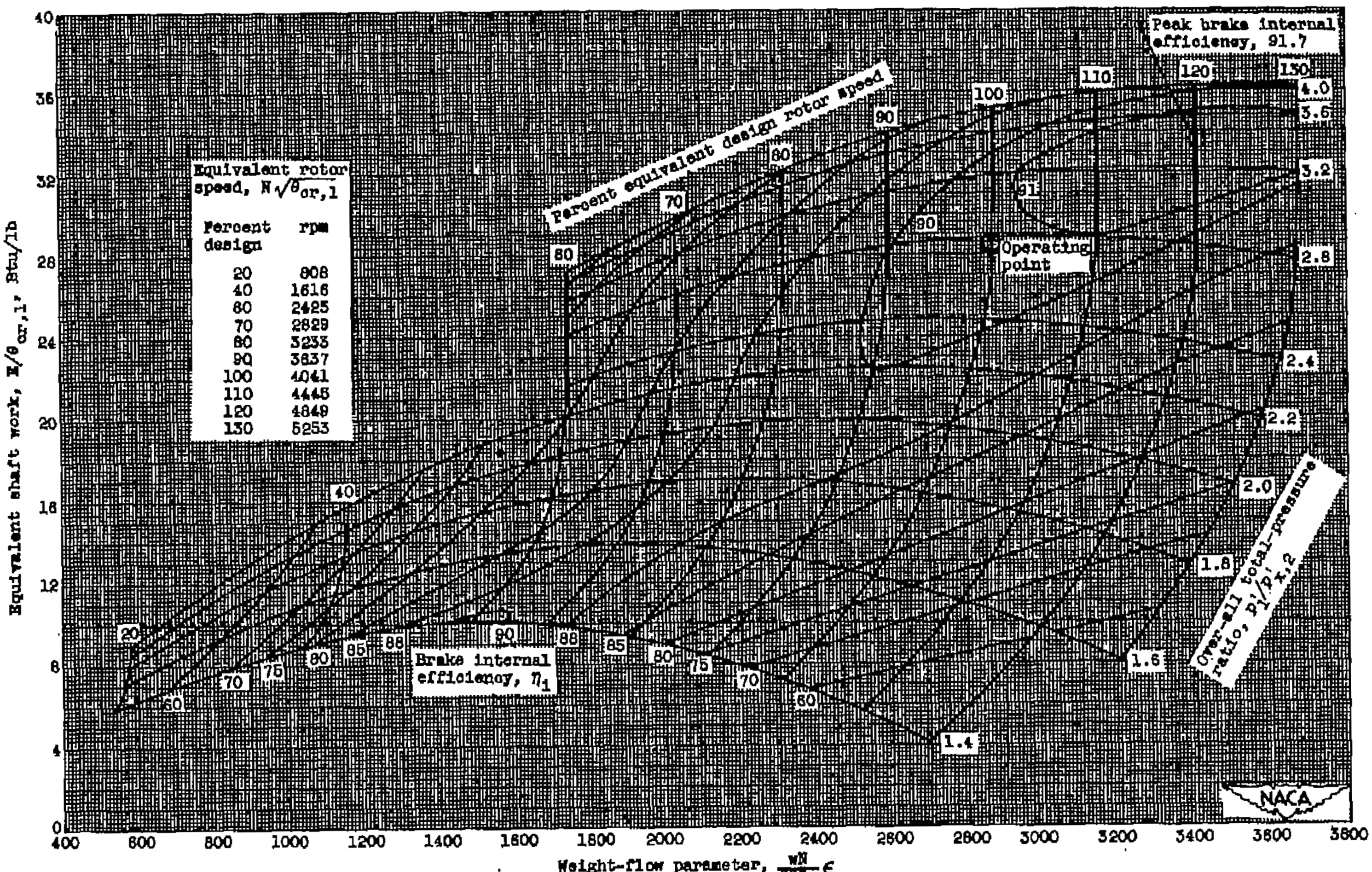

(b) Equipped with standard rotor blading (ref. 1).

Figure 3. - Concluded. Over-all performance of J73 two-stage turbine. Turbine-inlet pressure, 35 inches of mercury absolute; turbine-inlet temperature, 700° R.

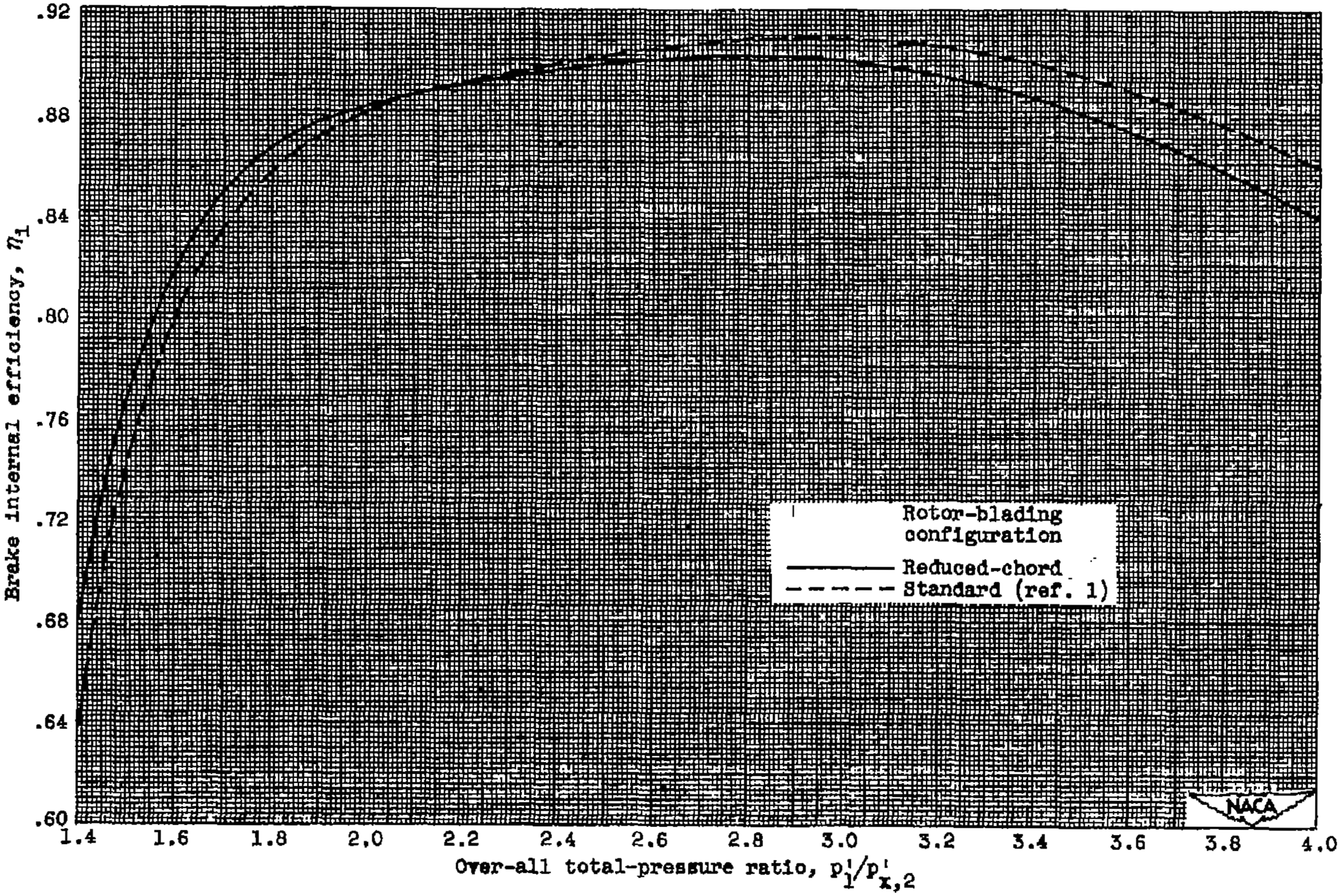

Figure 4. - Variation of over-all brake internal efficiency with over-all total-pressure ratio at design speed for J73 turbine with two rotor configurations.

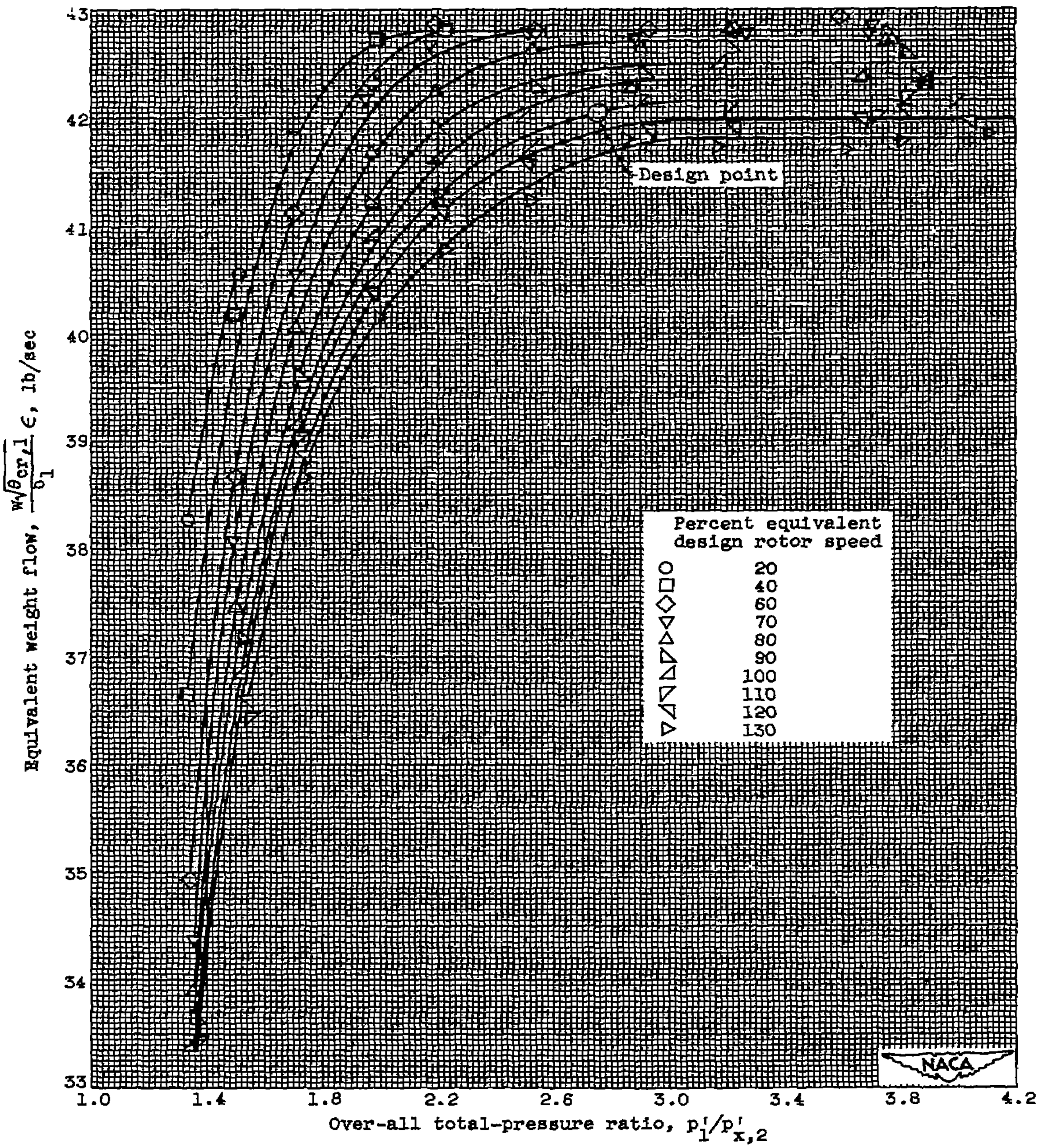

Figure 5. - Variation of equivalent weight flow with over-all total-pressure ratio for various equivalent rotor speeds.

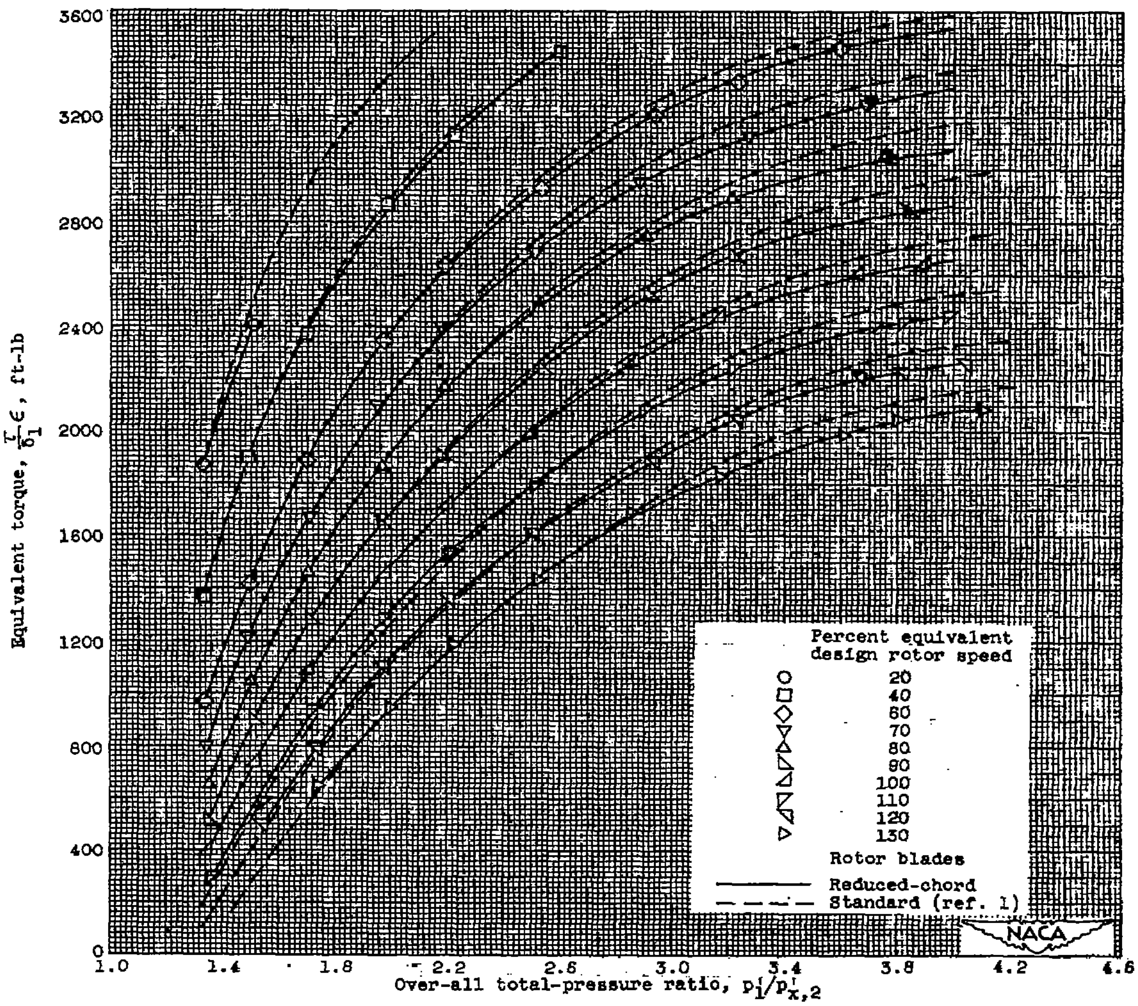

Figure 6. - Variation of equivalent torque with over-all total-pressure ratio for two rotor-blading configurations at various equivalent rotor speeds.

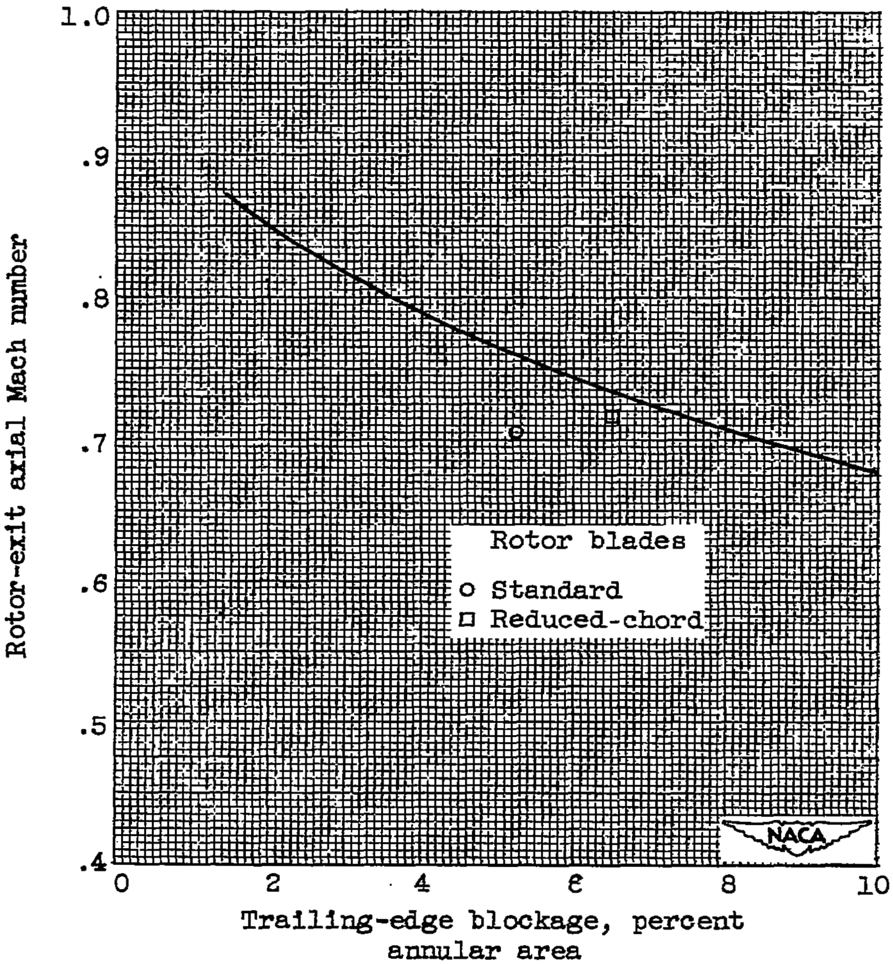

Figure 7. - Variation of rotor-exit axial Mach number with second-stage rotor trailing-edge blockage for turbine blades operating at limiting loading (ref. 3).

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